Calorimeter Ground Software

J. Eric Grove

Naval Research Lab

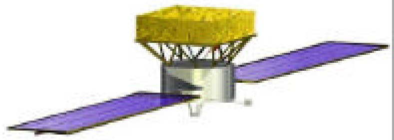
Scope and Requirements for Ground tasks.	Grove
Status of SIMUL_RECON.	Djannati-Atai

Scope of Ground Segment S/W

For the whole of GLAST, the Ground Segment software tasks include

- Ground Support Equipment software
  - Bench checkout
  - Tower and s/c simulators
  - **Simulation**
- Mission Operations
  - Mission planning
  - Commanding and state verification
  - Health and safety monitoring
  - Production data processing
    - **Calibration**
    - **Position reconstruction**
    - **Energy reconstruction**
    - **Background rejection, L3Trig processing**
- Science Data Analysis
  - **Spectral deconvolution**
  - **Spectral model fitting**
  - Timing analysis
  - Diffuse source analysis
  - […]
  - Sky maps and catalogs

Rule #1: Test it as you're gonna fly it.



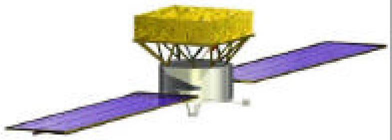
Ground Segment S/W Requirements

Given that we're gonna test it the same way we're gonna fly it, we need to **specify requirements on ground s/w.**

- Software requirements are driven by
  - Science Requirements Document
    - What data products are required.
    - What performance is necessary.
    - What tools and guidance the scientist needs.
  - Instrument implementation
    - How incident photons are turned into a data stream.
  - Mission scenario
    - How data are delivered, in what form, and how often.
- ***Specifying S/W requirements is not merely specifying coding practices.***

Standard Documentation

- Software Requirements Document (SRD)
  - Functional requirements spec
  - Interface requirements spec
- Software Development Plan (SDP)
  - Detailed definition of modules
  - Assignment of responsibilities
  - Development standards
  - Quality assurance
- Software Test Plan (STP)



Ground Segment S/W Requirements

- Simulation
  - No more on-axis thinking.
  - Make output = instrument data stream.
    - Xtal-by-xtal measurement v. MC truth.
- Calibration
  - What needs to be calibrated?
  - How often, and with what precision?
  - What is the calibration process?
  - What s/w do we need?
- Background rejection
- Event reconstruction
  - Positions, energies
- Spectral Deconvolution
  - Profile fitting v. Response Matrix

Requirements for SIMUL_RECON

- Improve fidelity of instrument model.
- Separate SIMUL from RECON.
  - Allows possibility of using RECON for data analysis.
- No more on-axis thinking. No more on-axis software.
  - The sky is off axis.
- **Need access to crystal-by-crystal Measurement and Monte Carlo Truth.**
  - “Measurement”
    - SIMUL output looks like instrument data stream, flight-like readout.
    - Allows comparison with Monte Carlo Truth.
- **Need to address spectral deconvolution.**
  - Profile fitting, instrument response matrix, hybrid ….

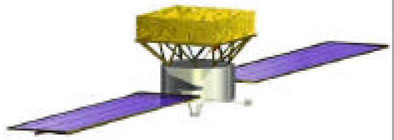
What needs to be calibrated?

- Energy measurement.
  - Need relative calibration among crystals and overall absolute calibration.
  - Requirements for relative and absolute calibration?
    - My thoughts:
      1. Relative calibration to <1% (at all energies).
      2. Absolute calibration:
         1. Get pion bump in right place ⇒ at ~100 MeV, absolute knowledge to <10%.
         2. At 100 GeV, …?
         3. Goal: ~3% at all energies.
- Position measurement.
  - Need light asymmetry calibration in each crystal.
    - Bkg-rejection “requires” ~3 cm knowledge (~10% of crystal length).
      - ⇒ Need slope knowledge to ~10%.
    - Goal: Improve pointing for conversions in SuperGLAST.
      - ~3 mm knowledge ⇒ Want slope knowledge to ~1%.

Background Rejection

- The calorimeter contributes to background rejection at L3T.
    1. Splat in calorimeter must correspond to track.
        - For low-E showers, must correspond to prong.
    2. Transverse shower profile must correspond to EM shower, not hadronic.

- **What requirements does this place on Ground Segment S/W?**



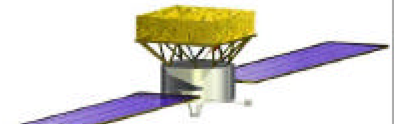
Spectral Deconvolution

Spectral deconvolution of astrophysical sources

- Requirements:
  - Test emission models against the observed spectra of astrophysical sources.
    - Need tools to turn observed counts and energy depositions into photons $cm^{-2}\ s^{-1}\ MeV^{-1}$
  - Publish these results in refereed journals.
    - These tools need to be familiar to the community and usable by GIs.
- What do we know?
  - Spectral information comes from the ensemble of all photons from a source, not from individual photons.
  - Source spectra are simple continuum shapes.
- **Spectral deconvolution is more than just energy reconstruction.**
  - Need to account for conversion efficiency (cm^2), resolution broadening, livetime.

End of overview

- End of overview



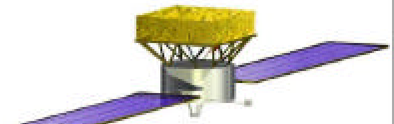
Mission Operations

For the whole of the GLAST, the Mission Operations Software tasks include

- Mission Planning
  - s/c pointing plan (epochs of scanning, pointed, ...)
  - Instrument configuration requirements
- Commanding
  - Command load generation, uplink, verification in IOC
  - Contingency planning and command scripting
- Health and Safety Monitoring
  - Instrument status monitoring
  - Environment monitoring (temperatures, bus voltages, blah blah)
    - inputs to calibration database
- Production Data Processing
  - Level 1 product generation and verification
  - High-level product generation and verification
  - Archiving
  - Data distribution

Requirements for SIMUL_RECON

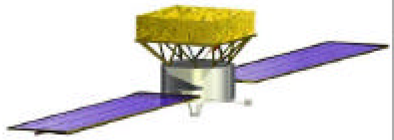
- Improve fidelity of instrument model.
- Separate SIMUL from RECON.
  - Allows possibility of using RECON for data analysis.
- No more on-axis thinking. No more on-axis software.
  - The sky is off axis.
- **Need access to crystal-by-crystal Measurement and Monte Carlo Truth.**
  - "Measurement"
    - SIMUL output looks like instrument data stream, flight-like readout.
    - Allows comparison with Monte Carlo Truth.
- **Need to address spectral deconvolution.**
  - Profile fitting, instrument response matrix, hybrid ….



SIMUL and RECON

Near-term software issues:

- **Need access to crystal-by-crystal Measurement and Monte Carlo Truth.**
  - Need access to “raw” data, Monte Carlo Truth.
    - IRF reader needs to be supported and maintained.
  - Need separate post-processor to turn Truth into flight-like response.
    - Individual crystal ends, gain ranges, appropriate light tapering.
  - Prohibit on-axis code.
    - “Corrected CsI” from Spring meeting in Santa Cruz is prime example of what never to do again.
    - More sanity and quality checks before software release.



SIMUL and RECON

Near-term Calorimeter simulation studies needed:

1. What is rate of multi-MIPs in ACD for everything but primary GCRs?
   - Sources of multi-MIP backgrounds?
   - Significant or negligible increase in data volume?
2. Effects of gaps.
   - Tower to tower, crystal to crystal.
   - Hytec mechanical design v. French mechanical design.
3. Effects of grid walls.
   - 6 mm of aluminum.
4. Energy corrections, measured ΔE to incident energy.
   - Leakage correction.
   - Tower-to-tower correction.
5. Optimize CAL-only triggers.

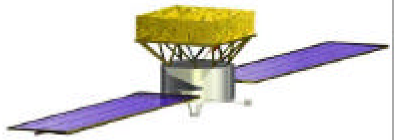
SIMUL and RECON

Other long-term issues

- Need to model system performance with failures (PIN, xtal, DAQ pipe,...)
- Need to be able to use simulation output for CAL trigger studies.
  - Currently conceptual triggers, buildable triggers, and simulateable triggers are not identical.
- Need to vet data sets before release.
  - e.g. need quality data sets for data volume and data transmission studies by DAQ group.
    - Noticed suspicious set being used.
    - Hard for DAQ people to know real effects vs artifacts.

What needs to be calibrated?

- Energy measurement.
  - Need relative calibration among crystals and overall absolute calibration.
  - Requirements for relative and absolute calibration?
    - My thoughts:
      1. Relative calibration to <1% (at all energies).
      2. Absolute calibration:
         - » Get pion bump in right place ⇒ at ~100 MeV, absolute knowledge to <10%.
         - » At 100 GeV, …?
         - » Goal: ~3% at all energies.
- Position measurement.
  - Need light asymmetry calibration in each crystal.
    - Bkg-rejection "requires" ~3 cm knowledge (~10% of crystal length).
      - ⇒ Need slope knowledge to ~10%.
    - Goal: Improve pointing for conversions in SuperGLAST.
      - ~3 mm knowledge ⇒ Want slope knowledge to ~1%.



Calorimeter Calibration

Energy Calibration

- Need absolute calibration of each gain scale for each PIN.
- Calib process runs continuously.
- Method:
  - Use cosmic rays from H to Fe.
  - Trigger ID by ACD.
  - Tracked in TKR.
  - Useful event rate expected to be ~100 Hz.

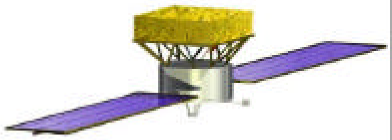
Position Calibration

- End-to-end light asymmetry in CsI bar gives longitudinal position.
  - $x = (dx/dr)\,(R - L) / (R + L)$
  - Position determination is *independent* of energy deposition.
- Must calibrate each PIN.
- Method: Again, GCRs and Tracker trajectories.

How often do calibration parameters need to be updated?

Timescales of Weeks.

- CsI light yield varies with radiation dose.
  - Test at NRL's ^{60}Co Irradiation Facility to ~20 kRad (~20 years or more on orbit) showed 25% degradation in light yield.
  - So ~1% per year, very long timescale.
- CsI light yield varies with temperature, ~1/2 % per deg C.
  - Large thermal mass $\Rightarrow$ no ΔT effect on orbital time scales.
  - Long-term ΔT possible from thermal surface degradation or seasonal exposure.
  - Active thermal control minimizes this effect.
- PIN diode bonds may degrade with time.
  - CLEO degradation was slow. Hamamatsu has fixed problem.
  - Failure on launch is more likely. Calibrate it out once.
- FEE gain and linearity may vary with radiation dose.
  - DMILL process is tolerant to relatively small dose on orbit.
  - Any change will be on long timescale.
- FEE gain and linearity may vary with temperature.
  - Again, thermal mass of calorimeter means timescale is long.



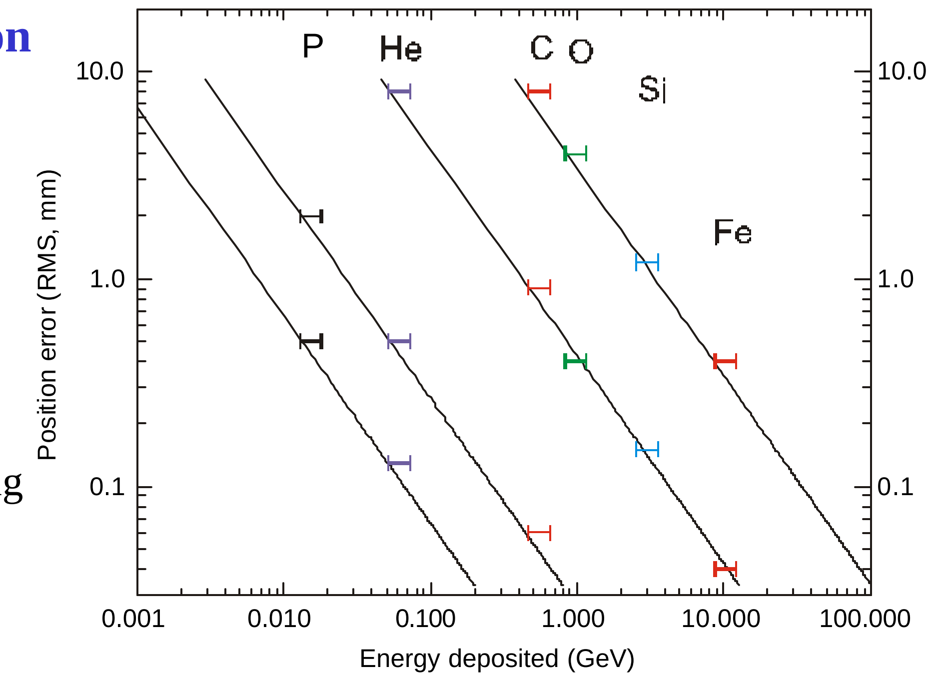
Calibration with Cosmic Rays

High flux of GCRs gives good calibration of full dynamic range.

- Concept:

1. ACD flags events > few MIPs.
2. ACD flags 1 in 1000 single-MIPs.
3. Accept only events with good TKR.
4. Accept only events with no charge-changing interactions in CAL.
5. Correct ΔE for pathlength in CsI bar.
6. Accumulate dE/dx in each bar.

- Derive calibration with statistical precision of better than few % each day over full dynamic range.

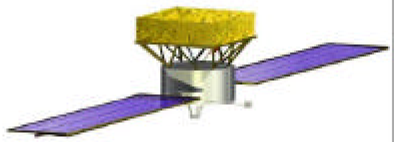


He: ~140 Hz
CNO: ~10 Hz ⇒ ~1100 per xtal per day
Si: ~0.4 Hz
Fe: ~0.8 Hz ⇒ ~70 per xtal per day

Calibration Process: S/W Needs

What software do we need for calibration process?

- **Physics inputs:**
  - dE/dx for heavy ions. Code expressions from the literature.
  - dL/dE for heavy ions. Measure it, then code it.
- **Elements of calibration process:**
  1. Extract multiMIP events.
  2. Identify likely GCRs, reject obvious junk.
  3. Fit tracks.
  4. Identify charges.
  5. Identify charge-changing interactions.
  6. Identify mass-changing interactions.
  7. Fit dE/dx.
  8. Accumulate energy losses and light asymmetries.



Calibration with Cosmic Rays

- **Questions for detector:**
  - What is magnitude, and dE/dx-dependence of scintillation efficiency? What is dL/dE?
- GSI beamtest for calorimeter.
  - Develop algorithms for
    1. Identifying charge-changing interactions.
    2. Identifying mass-changing interactions.
  - Derive dL/dE for heavy ions.
- **Questions for simulation:**
  1. What is rate of >few MIPs in ACD for everything but primary GCRs? Does this trigger add significantly to data volume?
  2. How well are CsI bars on outer edge of calorimeter covered by tracked GCRs?
- Is there a concern about calibrating above ~10 GeV?
  - Fe deposits ~10 GeV, but HE range goes to ~100 GeV.

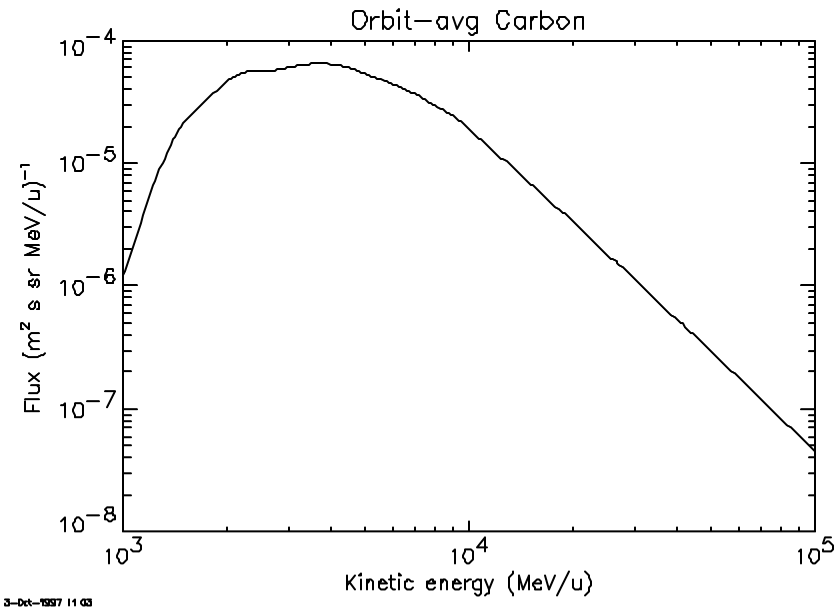
Calibration with Cosmic Rays

Particle fluxes

- CREME96 for 28.5 deg orbit for abundances and spectra.
- Conservative estimates: Required GCR to pass through upper and lower faces of CAL.

Particle ranges

- At 2 GeV/n in CsI, ranges of C and Fe are 440 g/cm^2 and 110 g/cm^2, resp.
- All incident C will penetrate CAL ($9X_0$ = 76 g/cm^2).
- All but low-energy, large-angle Fe will penetrate.



Z range	Rate (s^{-1})
1 – 28	1020
6 – 28	12.4
10 – 28	3.6
24 – 28	0.7

Calibration with Cosmic Rays

- **Nuclear interactions**
  - Majority of GCRs suffer nuclear interactions as they pass through calorimeter.
  - Interaction lengths:
    - $\lambda_{N,CsI} = 86\ g/cm^2$
    - $\lambda_{Fe,CsI} = 58\ g/cm^2$
  - GCR at 45 deg traverses ~100 g/cm^2 of CsI
    - ~30% of CNO group and ~20% of Fe survive without interacting.
- **How many per day in each CsI bar?**
  - **~1100 non-interacting CNO.**
  - **~70 non-interacting Fe.**

- **Scintillation efficiency**
- Light output of CsI(Tl) is not strictly proportional to ΔE for heavy ions.
  - dL/dE, the light output per unit energy loss, decreases slowly with increasing dE/dx for heavy ions, but is constant for EM showers.
  - dL/dE is fcn of dE/dx, rather than charge of the beam.
  - Magnitude (in NaI!!):
    - ~0.9 near minimum ionizing.
    - ~0.3 near end of range.
- Need to measure in heavy ion beam!

Calibration with Cosmic Rays

- **Calibration Uncertainty**
- Need to bin GCRs by estimated ΔE. This is uncertain for following reasons:
  - Uncertainty in initial energy.
    - ΔdE/dx ~ 10% over 2 - 6 GeV/n.
  - Landau fluctuations.
    - σ_L < 5% for CNO near 5 GeV/n.
    - σ_L < 5% for Fe near 5 GeV/n
  - Unidentified nuclear interactions.
    - p-stripping from C is hard to miss.
    - p-stripping from Fe.
      - ΔE < 10%.
  - Uncertainty in dL/dE.
    - Guess < few %.
- Adding in quadrature gives rms < 20%.
- With ~1000 CNO per bar per day, statistical **precision of ~1% per day is achievable**.

GSI Beam Test for Calorimeter

- **From:** Grove, Eric
  Sent: Tuesday, October 19, 1999 9:07 AM
  To: Johnson, W. Neil; Phlips, Bernard
  Subject: thoughts on GSI beamtest
  Heavy ion beamtest goals:
  (1) Gain familiarity with heavy ions in scintillator.
  (2) Measure saturation for heavy ions in CsI.
  (3) Develop algorithms to identify charge and/or mass changing interactions in calorimeter.

- **What beams can GSI deliver and what do we want?**
  The SIS at GSI delivers 1 to 2 GeV/u beams. Species range at least from carbon to uranium.
  Range of beams:

	C	C	Fe	Fe	
E	1	2	1	2	(GeV/u)
R	180	440	45	110	(g/cm2)

- Thickness of calorimeter is 8 x 2.3 x 4.51 x sectheta = 83.0 sectheta g/cm2, so all C beams will penetrate without much slowing down (so without much change in dE/dx), while Fe beams can be made to slow and stop at several depths in the stack.

  We might also want to run with Fe beam and plastic upstream to increase spallation rate. This gives sub-Fe to test scintillation efficiency.

  Thus Fe is good to study change in saturation with changing dE/dx. We can compare to a C point, and maybe some intermediate species, like Ne, if they can deliver the beam. Fe is also good to develop algorithms to find spallation interactions.
- Presumably we should hit several points in the calorimeter to be sure to sample crystals from STCU and Crismatec from different batches, and presumably we should use the same points we hit at SLAC for cross-calibration. Presumably we should do several off-axis runs, since that always makes the algorithms more complicated, and more realistic.

- **Beam plan thought**
  Minimum beam plan to cover goals above.
  On axis:
  Three beams -- C at 2 GeV/u, Fe at 1 GeV/u and 2 GeV/u -- each at 9 or 16 positions. With Fe beam at 1 GeV/u, also add some positions with plastic upstream.
- ***From behind:***
  Two beams -- Fe at 1 GeV/u and 2 GeV/u -- each at 9 or 16 positions. Add plastic upstream to some 1 GeV/u positions. No need for C since it doesn't slow much.
- At an angle:
  One beam -- Fe at 2 GeV/u -- at several large angles and positions.
- ***Useful additions to the minimum test plan:***
  1. Ne beam (which energy?) to fill in intermediate dE/dx. On axis at several positions.
  2. C beam at an angle.
  3. C and/or Ne beam at 1 GeV/u with 100 g/cm2 of Pb upstream. This is a poor way to make a stopping lower-Z beam, but maybe the only easy way at GSI. This tests saturation at intermediate dE/dx.
- **What other hardware do we need?**
  Thin plastic scintillator upstream and downstream of stack to ensure we know the charge before and after the calorimeter. This is desireable, but not necessary. After all, we say we don't need the ACD in flight for this. Plastic 1 cm thick is more than adequate.
- If the beam spot is small, we don't need a hodoscope.

  Questions
  With current electron yield, which dE give good cross-calibrations between ranges? Do we really care, or do we just want to watch dE/dx?
- Still need to calculate run times in each configuration, given expected interaction probabilities. Still need to find out how complicated it is to switch beam species and energy.
-
- Eric

Background Rejection

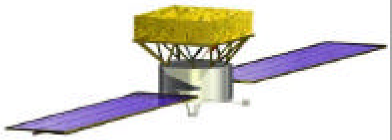
- The calorimeter contributes to background rejection at L3T.
  1. Splat in calorimeter must correspond to track.
     - For low-E showers, must correspond to prong.
  2. Transverse shower profile must correspond to EM shower, not hadronic.

- **What requirements does this place on Ground Segment S/W?**

Spectral Deconvolution

Spectral deconvolution of astrophysical sources

- Requirements:
  - Test emission models against the observed spectra of astrophysical sources.
    - Need tools to turn observed counts and energy depositions into photons cm^{-2} s^{-1} MeV^{-1}
      - Need to account for conversion efficiency, livetime, and energy redistribution.
  - Publish these results in refereed journals.
    - These tools need to be familiar to the community and usable by GIs.
- What do we know?
  - Spectral information comes from the ensemble of all photons from a source, not from individual photons.
  - Source spectra are simple continuum shapes.
    - Single power laws, power laws with breaks or cutoffs, etc.
    - Broad pion bump, but no lines.



Spectral Deconvolution

- Resolution broadening is important for steep spectra.
  - More-abundant low-energy photons look like high-energy photons.
  - Observed spectrum is artificially flattened.
  - *So even if you make your best guess of the energy of each photon, you can still get the wrong spectral index.*
  - *Still need to do resolution deconvolution.*

- **Spectral deconvolution is more than just energy reconstruction.**
  - Shower profiling helps correct observed ΔE into incident photon energy, but …
  - Need to account for
    1. resolution broadening, which can be *increased* by profiling.
    2. conversion efficiency (cm^2)
    3. livetime.

Instrument Response:

Event By Event vs Response Matrix vs Other (Both)

This is not just a cultural issue (HEP vs Astro), and it needs to be recognized as *separate* issue from “calibration” or “reconstruction”.

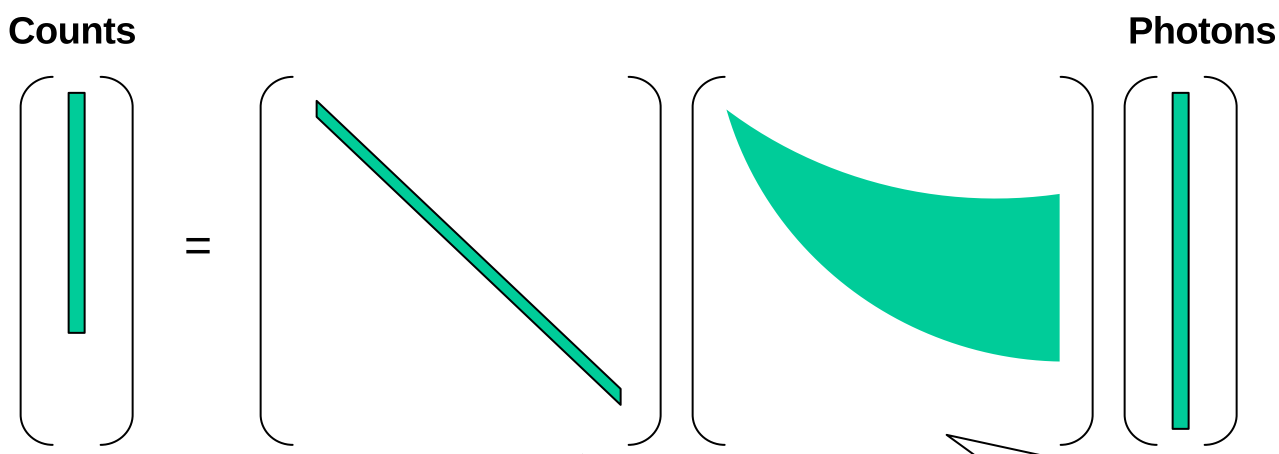
Both approaches have advantages and disadvantages :

- EBE more computer intensive and more accurate for any single photon, but not necessarily for an ensemble.
- EBE still needs to correct for off-angle efficiency (i.e. effective area), livetime, and resolution broadening.
- Response matrix without EBE first would not use all the information.
- Response matrix must account for all aspects to target.

Spectral Deconvolution

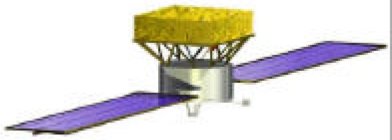
Instrument response matrix.

- Conversion of incident photon flux to observed count spectrum.



Effective Area matrix.
- Geometric area x conversion efficiency.
- Livetime weighted over all aspects to src.

Energy redistribution matrix.
- Incident high-energy photons are observed as lower energy.
- Includes resolution broadening.
- Livetime weighted over all aspects to src.



Spectral Deconvolution

Spectral deconvolution

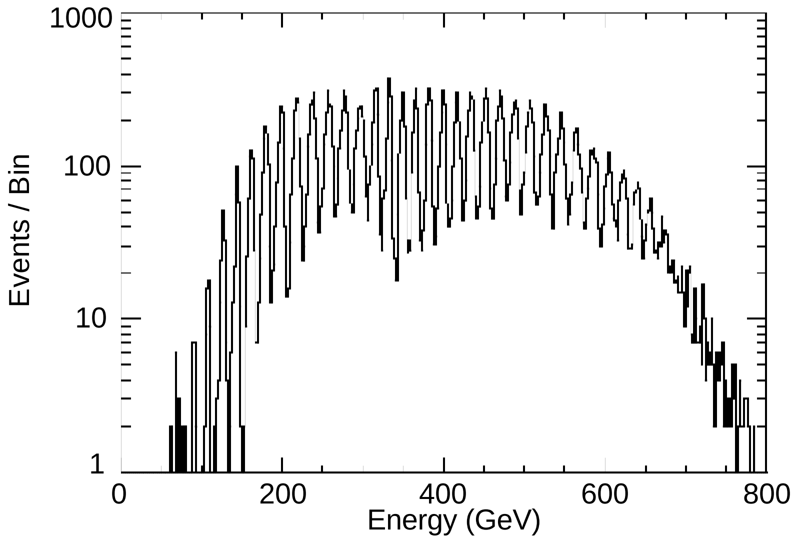
- Forward-Folding Deconvolution from an ensemble of detected gamma rays.
  - Create Instrument Response Matrix
    - Transforms measured energy deposition into incident energy as a function of zenith and azimuth.
    - Columns of response matrix are Green's functions at a large number of incident energies.
      - » i.e. the spectra that should be produced by monoenergetic beams
  - Candidate incident spectrum is multiplied by the response matrix and compared to the observed spectrum.
  - Parameters of the candidate spectrum are varied to minimize χ^2.

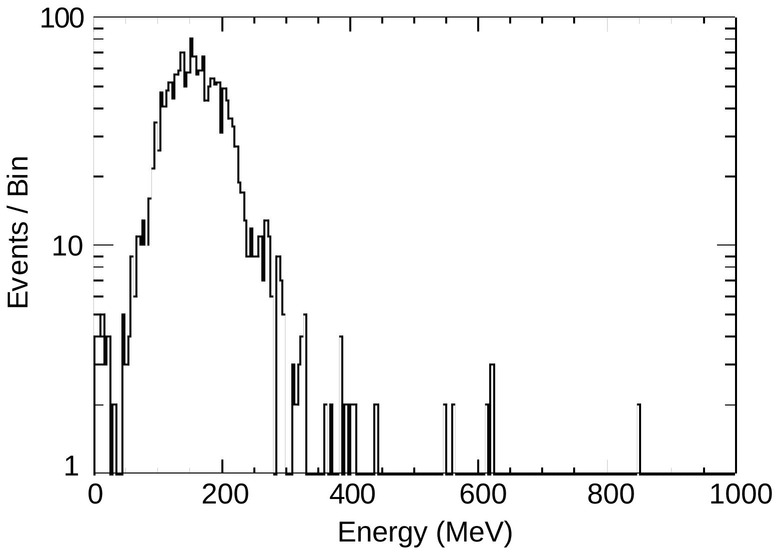
Energy Reconstruction

- Principle function of Calorimeter is to measure the energy of incident gammas.

- How do we reconstruct photon energies and source spectra?
  - Simply summing all the CsI signals isn't enough because
    1. Lots of energy leaks out the back of the calorimeter.
    2. Energy resolution is dominated by statistics of shower fluctuations.
    3. Conversion efficiency is a function of aspect and energy.
  - We have discussed two methods:
    1. Shower profile fitting, event by event.
    2. Spectral deconvolution, for an ensemble of photons.

BTEM Calorimeter Energy Resolution and Energy Reach





Dec'99 Beam Test Performance

- 20 GeV Positrons, 10 - 25 e^+/spill
- Self triggering

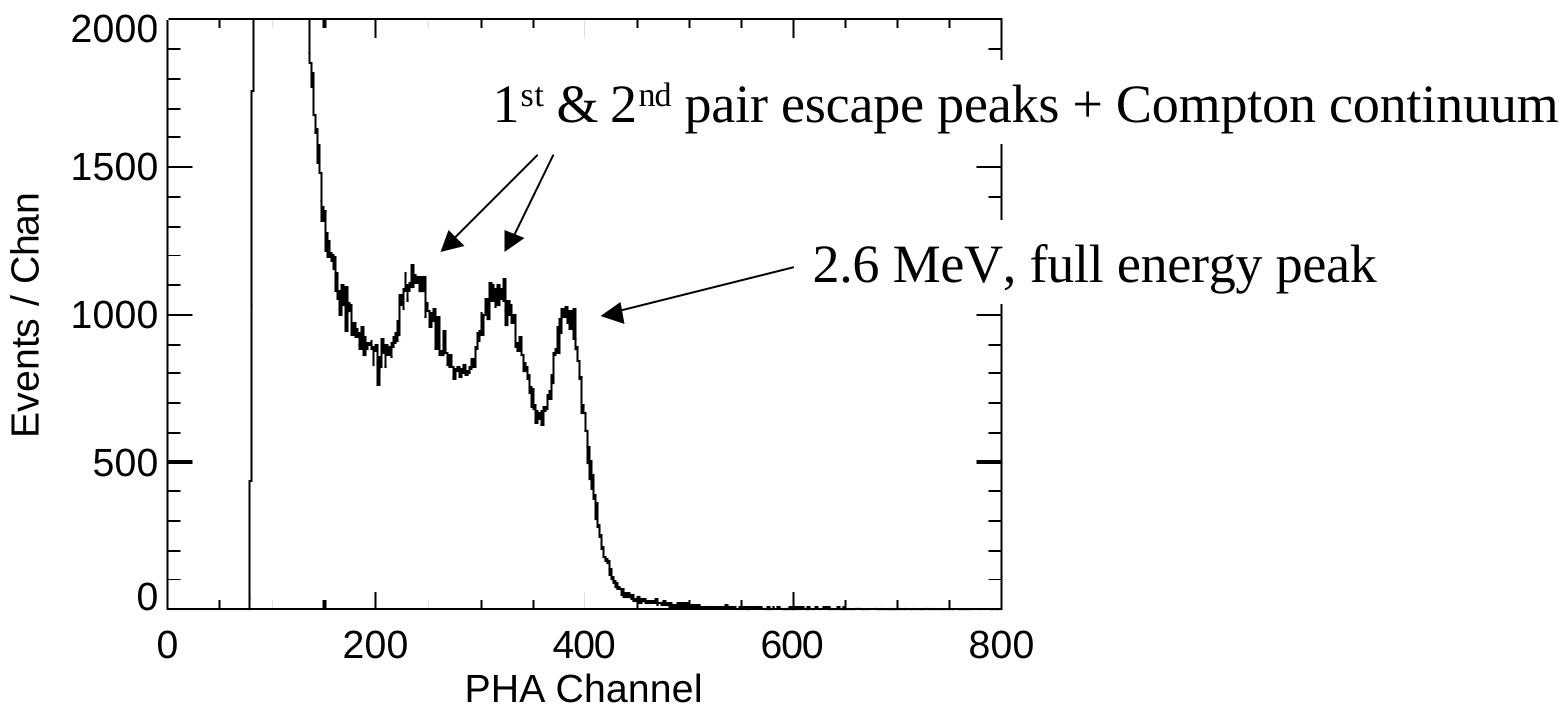
Top Panel:

- GLAST can easily resolve up to 35 positron peaks.

Bottom Panel:

- Trigger threshold of ~ 3 MeV also triggers on cosmic muons depositing ~ 12 MeV/crystal
- Peak width represents path length variation from large angular FOV.

Calorimeter Low Energy Response



Acceptance Testing of CsI crystals and PIN photodiodes
with ^{228}Th Calibration Source